Multilabel Rib Segmentation Using Domain-Adversarial Training

Degree programme: BSc in Computer Science
Specialisation: Computer Perception and Virtual Reality
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Adolescent scoliosis patients require frequent imaging throughout growth, but CT scans deliver radiation equivalent to hundreds of chest X-rays. This thesis develops an automated pipeline for extracting 3D anatomical models from safer, low-dose biplanar EOS X-ray images using synthetic data generation, domain adversarial training, and 3D reconstruction methods.

Problem and Motivation

Despite EOS imaging's advantages of reduced radiation exposure and standing-position acquisition, two critical challenges prevent automated analysis. First, overlapping anatomical structures in 2D projections create segmentation discontinuities where conventional methods fail to preserve individual rib continuity. Second, the severely limited availability of labeled EOS datasets severely hinders robust machine learning model development.

Methodology

The thesis employs a three-phase pipeline addressing these limitations. The first phase generates synthetic training data from over 750 CT volumes using automated rib segmentation with TotalSegmentator, supplemented by a specialized nnU-Net for missing costovertebral joints. Digitally Reconstructed Radiography (DRR) generation employs parallel ray casting through the CT scans to create synthetic X-ray images. To address overlapping structures, segmentation masks are projected using separate channels for each rib pair, maintaining complete anatomical information where conventional methods would fail. Scoliosis simulation applies pathological deformations to address the absence of scoliosis cases in the source data.
The second phase implements domain adversarial segmentation using a custom U-Net architecture with 12 output channels for independent rib pair prediction. Multiple domain classifiers receive features from different network levels, while a gradient reversal layer creates adversarial dynamics where the segmentation model learns domain-invariant representations.
The final phase transforms biplanar segmentations into volumetric ribcage models through mathematical correspondence between orthogonal projections. Centerline extraction applies skeletonization followed by parametric representation through cubic spline fitting. By combining x- and z-coordinates from the biplanar views, complete 3D positions are reconstructed. Elliptical cross-sections are then generated along each rib centerline to create triangular mesh models.

Results

The segmentation network achieved a Dice score of 0.93 on synthetic DRR validation data, demonstrating strong source domain performance. Domain adversarial training significantly reduces the domain gap, with coronal EOS segmentation achieving sufficient accuracy for direct 3D reconstruction use. However, sagittal view segmentation, particularly in upper rib regions affected by arm positioning, requires further refinement. When applied to high-quality DRR segmentations, the reconstruction algorithm produces anatomically coherent 3D ribcage models, maintaining individual rib geometry and spatial relationships, demonstrating the technical feasibility of the complete pipeline approach.

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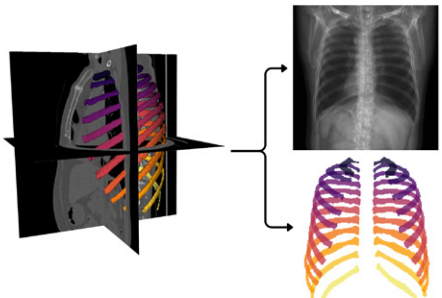
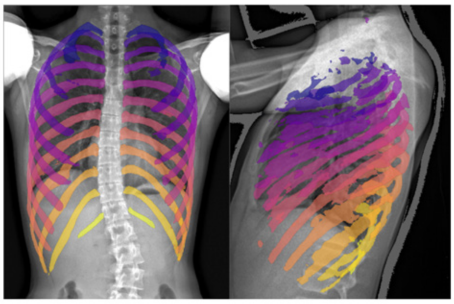


Generation of DRR and segmentation mask from CT volume



Segmentation of biplanar EOS X-Ray images